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Effect of iron, molybdenum and *Rhizobium* on nutrient content and uptake by summer groundnut (*Arachis hypogaea* L.) in loamy sand soil

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Abstract
A field experiment was carried out to see the effect of iron, molybdenum and *Rhizobium* on nutrient content in summer groundnut. The field experiment comprised of eighteen treatment combinations with three levels of iron 0, 5 and 10 kg Fe ha^{-1}, three levels of molybdenum 0, 1 and 2 kg Mo ha^{-1} and two levels of *Rhizobium* without *Rhizobium* and with *Rhizobium* inoculation were studied with GG-34 variety of groundnut in randomized block design in factorial concept with three replications. Among the all the treatments application of 10 kg Fe ha^{-1} along with 1.0 kg Mo ha^{-1} and seed inoculation with *Rhizobium* proved superior over other treatments.

Keywords: Iron, molybdenum, *Rhizobium*, groundnut

Introduction
Groundnut (*Arachis hypogaea* L.) is an important oilseed crop belonging to family *Fabaceae* (or *Leguminosae*). Groundnut is the king of oilseed crops and vegetable oil economy of country depends very much on it. It is mostly grown for seeds and oil production in the world. It is also known as peanut, monkeynut, earthnut, goober and manillanut. India ranks second in groundnut production in world. In India, during 2020-21 groundnut crop cultivated in about 6 million hectares with the total production of 10.24 mt and productivity of 1703 kg ha^{-1} (Anonymous, 2021). Iron is one of the most deficient nutrients in Indian soils. It is a structural component of cytochrome, hematin and leghaemoglobin. It is also important in activation of several enzymes including: fumaric hydrogenase, catalase, dehydrogenase, oxidase and peroxidase. It helps in absorption of other plant nutrients. Iron is also associated with chloroplast and protein synthesis. Molybdenum is an essential plant nutrient found in soil. It is also known as ultra-micronutrient as this is required in very less amount. As its less amount is required, the deficiency and sufficiency range are narrow. Molybdenum requirement of legumes are mostly higher than grasses. Molybdenum is more accessible in anion form (MoO_4^{2-}) to plants in alkaline soils as it become more soluble at higher pH. While in acidic soils its availability decreases due to anion adsorption. The inoculation of *Rhizobium* for legumes have been used worldwide. Seed inoculation with an efficient *Rhizobium* strain is the cheapest and most important input in leguminous crop production. Inoculation of legume crops with proper strain of *Rhizobium* can fulfill up to 90% of their nitrogen requirements (Anandham *et al*., 2007) [1].

Materials and Methods
A field experiment was conducted at Agronomy Farm, BACA, Anand Agricultural University, Anand, Gujarat during summer seasons of 2021 and 2022 in randomized block design in factorial concept with three replications. The experimental field was well drained and sandy loam in texture. Geographically, Anand is situated at 22^0 35’ N latitude, 72^0 55’ E longitude with an elevation of 45.1 m above the mean sea level. The eighteen treatment combinations involving three factors, each of Fe and Mo at 3 levels and *Rhizobium* at 2 levels were taken, in which Fe at 0, 5 and 10 kg ha^{-1}, molybdenum at 0, 1 and 2 kg ha^{-1} and two levels of *Rhizobium;* without *Rhizobium* and with *Rhizobium* inoculation were taken. Iron and molybdenum were applied in soil before sowing through $FeSO_4$ and Ammonium molybdate $(NH_4)_6Mo_7O_{24}.4H_2O$), respectively. The *Rhizobium* biofertilizer was inoculated through seed treatment (5 ml kg^{-1} seed). Recommended dose of fertilizer for summer groundnut was 25:50:0 kg of N, P_2O_5 and K_2O/ha, respectively.

The whole dose of fertilizer was applied at the time of sowing. The samples of grain and straw after collecting from each plot, air dried and subsequently oven dried at 70 ºC. Powdered plant samples were stored in polythene bags for further chemical analysis.

Computation of nutrient uptake: The concentration of nutrient in plant were expressed in percentage for macro nutrients and mg kg^{-1} for sulphur and micro nutrients. The nutrient uptake was calculated using the following formula:

$$\text{Macro nutrient and Sulphur uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

$$\text{Micro nutrient uptake (g ha}^{-1}\text{)} = \frac{\text{Nutrient content (ppm)} \times \text{Yield (kg ha}^{-1}\text{)}}{1000}$$

Results and Discussion

Nitrogen content: It is clear from the data (Table 1) that significantly highest nitrogen content 3.51% in kernel and 2.03% in haulm was recorded in pooled results with application of 10 kg Fe ha^{-1} as compared to control and 5 kg Fe ha^{-1}. Application of 1 kg Mo ha^{-1} recorded 3.51% N in kernels and 1.99% N in pooled but these results of nitrogen content in kernels were at par with 2 kg Mo ha^{-1} only in 2022. Significantly higher nitrogen content of groundnut kernels and haulm due to molybdenum application might be due to the fact that Mo is part of nitrogenase enzyme that improves BNF and resulting higher N content in kernels and haulm. Similar beneficial effect of Mo on N content was also reported by Kumar and Sharma (2005) [12]. Nitrogen content in kernels and haulm differ significantly due to seed inoculation with *Rhizobium* compared to no inoculation during both the individual years and in pooled. Significantly highest N content in kernels 3.47% and in haulm 1.94% on pooled basis was noted under the seed inoculation with *Rhizobium.* It might be due to more biological nitrogen fixation by *Rhizobium* in root nodules of plants and more nitrogen absorption and ultimately more nitrogen content in kernels and haulm. Similar results were reported by Deo and Kothari (2002) [5].

Phosphorus content: It is evident from the data (Table 1) that numerically, highest phosphorus content in kernels 0.44% and 0.23% in haulm was recorded in pooled with no application of iron in experimental field. The reduction in P content in kernel and haulm might be due to antagonistic relationship between iron and phosphorus that reduced absorption and translocation of phosphorus to different parts of plant. The results of present investigation are in agreement with those of Jatav (2000) [9], Eisa *et al*. (2011) [7] and Doodhwal *et al*. (2020) [6]. Different levels of molybdenum and *Rhizobium* inoculation had no significant effect on phosphorus content in kernels and haulm. Application of molybdenum @ 1 kg ha^{-1} gave the highest phosphorus content in kernels 0.43% and in haulm 0.23% in pooled while highest P content in kernels 0.43% and in haulm 0.23% was noted in pooled under the seed inoculation with *Rhizobium*.

Table 1: Effect of iron, molybdenum and *Rhizobium* on nitrogen and phosphorus content in groundnut kernel and haulm

Treatments	Nitrogen content (%)						Phosphorus content (%)					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	3.31	3.35	3.33	1.61	1.74	1.67	0.43	0.45	0.44	0.24	0.23	0.23
Fe_5	3.34	3.39	3.37	1.84	1.94	1.89	0.41	0.43	0.42	0.23	0.22	0.22
Fe_{10}	3.50	3.53	3.51	1.99	2.07	2.03	0.38	0.40	0.39	0.21	0.20	0.20
SEm ±	0.04	0.05	0.03	0.05	0.05	0.03	0.01	0.01	0.006	0.005	0.005	0.003
CD at 5%	0.12	0.15	0.09	0.14	0.15	0.09	0.025	0.02	0.017	0.013	0.013	0.009
Molybdenum (kg ha^{-1})												
Mo_0	3.31	3.34	3.33	1.71	1.82	1.76	0.39	0.42	0.41	0.22	0.21	0.21
Mo_1	3.48	3.53	3.51	1.94	2.03	1.99	0.42	0.44	0.43	0.23	0.22	0.22
Mo_2	3.37	3.39	3.38	1.78	1.89	1.84	0.41	0.43	0.42	0.22	0.21	0.22
SEm ±	0.04	0.05	0.03	0.05	0.05	0.03	0.01	0.01	0.006	0.005	0.005	0.003
CD at 5%	0.12	0.15	0.09	0.14	0.15	0.09	NS	NS	NS	NS	NS	NS
Rhizobium												
R_0	3.33	3.36	3.34	1.74	1.83	1.78	0.40	0.42	0.41	0.22	0.21	0.22
R_1	3.44	3.49	3.47	1.89	2.00	1.94	0.42	0.44	0.43	0.23	0.22	0.23
SEm ±	0.03	0.04	0.03	0.04	0.04	0.03	0.01	0.01	0.005	0.004	0.004	0.003
CD at 5%	0.10	0.12	0.08	0.11	0.12	0.07	NS	NS	NS	NS	NS	NS

Potassium content: The data (Table 2) explicit that fertilizers and biofertilizers application had no significant effect on K content in kernels and haulm during both the individual years as well as in pooled. Numerically, highest potassium content in kernels 0.77% and 0.97% in haulm was recorded with application of 10 kg Fe ha^{-1} in 2021, 2022 and in pooled, respectively.

Sulphur content: The data (Table 2) explicit that S content in kernels and haulm did not change significantly due to iron application during both the individual years as well as in pooled. Significantly, highest S content in kernels *i.e.*, 0.175, 0.186 and 0.181% and 0.157, 0.156 and 0.157% in haulm was recorded with application of 10 kg Fe ha^{-1} in 2021, 2022 and in pooled, respectively.

Table 2: Effect of iron, molybdenum and *Rhizobium* on potassium and sulphur content in groundnut kernel and haulm

Treatments	Potassium content (%)						Sulphur content (%)					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	0.74	0.76	0.75	0.91	0.93	0.92	0.159	0.165	0.162	0.133	0.135	0.134
Fe_5	0.75	0.77	0.76	0.93	0.95	0.94	0.167	0.169	0.168	0.144	0.146	0.145
Fe_{10}	0.77	0.78	0.77	0.96	0.98	0.97	0.175	0.186	0.181	0.157	0.156	0.157
SEm ±	0.01	0.01	0.01	0.02	0.01	0.01	0.003	0.004	0.002	0.003	0.003	0.002
CD at 5%	NS	NS	NS	NS	NS	NS	0.008	0.011	0.007	0.009	0.008	0.006
Molybdenum (kg ha^{-1})												
Mo_0	0.73	0.76	0.74	0.90	0.92	0.91	0.162	0.170	0.166	0.140	0.141	0.141
Mo_1	0.76	0.77	0.77	0.96	0.97	0.96	0.172	0.177	0.175	0.151	0.150	0.150
Mo_2	0.75	0.77	0.76	0.93	0.96	0.94	0.167	0.173	0.170	0.145	0.156	0.149
SEm ±	0.01	0.01	0.01	0.02	0.01	0.01	0.003	0.004	0.002	0.003	0.003	0.002
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rhizobium												
R_0	0.74	0.75	0.75	0.92	0.94	0.93	0.165	0.170	0.167	0.142	0.143	0.143
R_1	0.76	0.78	0.77	0.95	0.96	0.95	0.170	0.177	0.174	0.148	0.150	0.149
SEm ±	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.003	0.002	0.002	0.002	0.002
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	7.05	7.85	7.47	7.41	6.54	6.98	7.50	9.61	8.56	8.91	8.59	8.75

Iron content: It is revealed from the data (Table 3) that significantly higher Fe content at 10 kg Fe ha^{-1} in groundnut kernels 381 mg kg^{-1} and in haulm 481 mg kg^{-1} was noted in pooled. The increase in Fe content in kernel and haulm might be due to increased availability of Fe in experimental field owing to its application. These results are in agreement with Singh *et al.* (2013) [16] and Poonia *et al.* (2022) [14]. Molybdenum and biofertilizer application had no significant effect on Fe content in kernels and haulm. Application of molybdenum @ 1 kg ha^{-1} gave the highest Fe content in kernels 371 mg kg^{-1}; and in haulm 468 mg kg^{-1} in pooled.

Manganese content: It is revealed from the data (Table 3) that Mn content in kernel of groundnut did not influence significantly with application of iron. Numerically, higher Mn content noted with control treatment in groundnut kernels while there was a significant decrease in Mn content with higher dose of Fe in haulm and highest Mn content in haulm noted with control treatment 67.7 mg kg^{-1} in pooled. Different levels of molybdenum and biofertilizer application did not exert any significant effect on Mn content in kernel during both the years and in pooled. The application of molybdenum @ 1 kg ha^{-1} recorded the highest Mn content in kernels 46.6 mg kg^{-1}; and in haulm 66.9 mg kg^{-1} in pooled. The results for Mn content in haulm part of plant were significant in pooled analysis. The highest Mn content in kernels 46.3 mg kg^{-1}; and in haulm *i.e.*, 64.9 mg kg^{-1} was found with seed inoculation with *Rhizobium* in pooled.

Table 3: Effect of iron, molybdenum and *Rhizobium* on Iron and Manganese content in groundnut kernel and haulm

Treatments	Iron content (mg kg^{-1})						Manganese content (mg kg^{-1})					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	348	352	350	441	436	438	46.0	47.0	46.5	67.0	66.4	67.7
Fe_5	357	370	363	456	454	455	45.3	46.6	45.9	65.4	64.5	64.9
Fe_{10}	374	388	381	479	483	481	43.3	44.7	44.0	62.3	61.7	61.9
SEm ±	6	6	4	7	8	5	0.8	0.9	0.7	1.3	1.2	0.9
CD at 5%	16	17	11	20	23	15	NS	NS	NS	3.7	3.4	2.5
Molybdenum (kg ha^{-1})												
Mo_0	354	363	358	452	445	449	43.8	45.0	44.4	63.3	62.7	63.0
Mo_1	365	377	371	465	471	468	45.9	47.3	46.6	67.3	66.7	66.9
Mo_2	360	370	365	458	457	458	45.0	45.9	45.5	64.1	63.2	63.6
SEm ±	6	6	4	7	8	5	0.8	0.9	0.7	1.3	1.2	0.9
CD at 5%	NS	NS	NS	NS	NS	15	NS	NS	NS	NS	NS	2.5
Rhizobium												
R_0	357	368	363	455	454	454	44.1	45.1	44.6	64.5	63.8	64.2
R_1	363	371	367	463	462	462	45.6	47.0	46.3	65.3	64.6	64.9
SEm ±	5	5	3	6	7	4	0.7	0.7	0.5	1.0	1.0	0.7
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	6.55	6.81	6.68	6.46	7.57	7.03	7.63	8.45	8.04	8.38	7.87	8.13

Copper content: Copper content in groundnut kernel did not change significantly due to application of iron during both years and pooled while the results for Cu content in haulm was non-significant during individual years but significant in pooled. Highest Cu content recorded with 10 kg Fe ha^{-1} application in groundnut kernels and in haulm. Different levels of molybdenum application did not exert any significant effect on Cu content in kernel during both years and pooled while the results for Cu content in haulm was non-significant during individual years but significant in pooled. Cu content in groundnut kernels did not differ significantly due to seed inoculation with *Rhizobium* during both the individual years and in pooled but the results for Cu content in haulm were significant in pooled.

Zinc content: It is revealed from the data (Table 4) that Zn content in kernel and haulm of groundnut reduced with higher levels of iron application. The results were significant for Zn content in haulm and non-significant in kernel. Higher Zn content noted in control treatment in groundnut kernels 66.1 mg kg^{-1}; and in haulm 53.5 mg kg^{-1} in pooled. Reduction in Zn content due to Fe application might be due to antagonistic effect with Zn that reduced mobility of Zn ion and resulted in lesser availability to plants. Similar findings were also reported by Singh *et al*. (2004) [15].
Different levels of molybdenum and *Rhizobium* inoculation did not have any significant effect on Zn content in kernel and haulm of groundnut.

Molybdenum content: Different levels of iron application and seed inoculation with *Rhizobium* did not have any significant effect on Mo content in kernel and haulm of groundnut. It is revealed from the data (Table 4) that Mo content in kernel and haulm of groundnut increased significantly with increasing levels of molybdenum application during both the individual years as well as in pooled. The significantly highest Mo content in groundnut kernel 0.44 mg kg^{-1} and in haulm 0.53 mg kg^{-1} recorded with the application of 2 kg Mo ha^{-1} during 2021, 2022 and pooled, respectively. The increase in Mo content in kernel and haulm of groundnut was obvious due to application of Mo in soil. The improved availability of Mo in soil might have resulted in higher Mo content in kernel and haulm of groundnut. Similar findings were also reported by Swami *et al.* (2021) [17].

Table 4: Effect of iron, molybdenum and *Rhizobium* on zinc and molybdenum content in groundnut kernel and haulm

Treatments	Zinc content (mg kg^{-1})						Molybdenum content (mg kg^{-1})					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	65.1	67.1	66.1	52.8	54.2	53.5	0.42	0.40	0.42	0.48	0.51	0.49
Fe_5	64.6	65.4	65.0	51.8	52.8	52.3	0.43	0.42	0.43	0.49	0.52	0.50
Fe_{10}	62.7	64.9	63.8	49.9	50.9	50.4	0.44	0.43	0.43	0.51	0.53	0.52
SEm ±	0.9	1.0	0.7	0.8	0.9	0.6	0.01	0.01	0.005	0.01	0.01	0.006
CD at 5%	NS	NS	NS	2.3	2.47	1.8	NS	NS	NS	NS	NS	NS
Molybdenum (kg ha^{-1})												
Mo_0	63.1	65.3	64.2	50.7	51.6	51.2	0.42	0.39	0.41	0.47	0.48	0.47
Mo_1	65.4	66.4	65.9	52.7	53.3	53.0	0.43	0.42	0.43	0.50	0.53	0.51
Mo_2	63.9	65.6	64.8	51.1	52.2	51.7	0.45	0.44	0.44	0.52	0.55	0.53
SEm ±	0.9	1.0	0.7	0.8	0.9	0.6	0.01	0.01	0.005	0.01	0.01	0.006
CD at 5%	NS	NS	NS	NS	NS	NS	0.02	0.02	0.014	0.02	0.02	0.018
Rhizobium												
R_0	63.7	65.1	64.4	50.7	51.9	51.3	0.43	0.41	0.42	0.49	0.51	0.50
R_1	64.6	66.5	65.5	52.3	53.4	52.8	0.44	0.42	0.43	0.50	0.53	0.51
SEm ±	0.8	0.8	0.6	0.7	0.7	0.5	0.01	0.01	0.004	0.01	0.01	0.005
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	6.11	6.32	6.22	6.64	6.91	6.78	7.18	6.92	7.06	7.01	7.00	7.01

Nutrient Uptake

Nitrogen Uptake: It is evident from the data (Table 5) that magnitude of increase in pooled results were 22.4 and 13.7 per cent in pod and 34.5 and 13.9 per cent in haulm at 10 kg Fe ha^{-1} application over control and 5 kg Fe ha^{-1}, respectively. Significantly higher uptake of N by plant due to Fe application might be due the fact that Fe is a constituent of nitrogenase enzyme that helps in more availability of nitrogen to the plant. Hence, more N content in plant along with higher yield resulted in more uptake of nitrogen. The results are in agreement with Meena *et al.* (2013) [13]. Mo application @ 1 kg ha^{-1} significantly improved N uptake by pods and haulm. On pooled basis the magnitude of increase in results were 21.1 and 14.1 per cent in pod and 24.5 and 15.3 per cent at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. Higher uptake of N due to Mo application might be due to active participation of Mo in nitrogen fixation and being structural part of nitrogenase that also improved nitrogen metabolism in plants. The results are in close agreement with Gupta *et al.* (2020) [8] and Bhagiya *et al.* (2005) [3]. N uptake by pods and haulm improved significantly under the influence of seed inoculation with *Rhizobium* during both years and in pooled. On pooled basis the magnitude of increase in uptake was 12.3 and 14.2 per cent in pod and haulm, respectively over no inoculation. The beneficial effect of *Rhizobium* inoculation on N uptake might be due to increase in N content in plant parts as well as improvement in yield. Similar findings were also reported by Khan and Prakash (2013) [11].

Phosphorus Uptake: It is explicit from the data (Table 5) that P uptake by pods and haulm was not affected significantly with iron application. Numerically higher P uptake was observed with application of Fe @ 10 kg ha^{-1} during both the individual years and in pooled. Significantly higher uptake of P by pods and haulm noted under application of Mo @ 1 kg ha^{-1} during both the individual years and in pooled. On pooled basis the magnitude of increase in results were 22.1 and 12.3 per cent in pod and 19.0 and 10.8 per cent at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. Higher uptake of P due to Mo application might be due to active participation of Mo in nitrogen fixation coupled with improvement in yield. The results are in close agreement with Bhagiya *et al.* (2005) [3]. Phosphorus uptake by pods and haulm improved significantly under the influence of seed inoculation with *Rhizobium* and on pooled basis the magnitude of increase in uptake was 13.1 and 9.27 per cent in pod and haulm, respectively over no inoculation. The beneficial effect of *Rhizobium* inoculation on P uptake might be due to combined effect of increased P content in plant parts as well as improvement in yield. Similar findings were also supported by Das *et al.* (2012) [4].

Table 5: Effect of iron, molybdenum and *Rhizobium* on nitrogen and phosphorus uptake by groundnut kernel and haulm

Treatments	Nitrogen uptake (kg ha^{-1})						Phosphorus uptake (kg ha^{-1})					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	53.72	53.68	53.70	55.99	61.92	58.96	7.06	7.19	7.13	8.16	7.96	8.06
Fe_5	57.82	57.85	57.83	67.39	72.00	69.69	7.13	7.36	7.25	8.25	8.01	8.13
Fe_{10}	65.78	65.77	65.77	77.32	81.41	79.36	7.15	7.51	7.33	8.34	8.04	8.19
SEm ±	1.64	1.69	1.18	1.79	2.11	1.39	0.24	0.23	0.16	0.25	0.22	0.17
CD at 5%	4.72	4.87	3.33	5.15	6.08	3.91	NS	NS	NS	NS	NS	NS
Molybdenum (kg ha^{-1})												
Mo_0	54.67	53.78	54.18	60.28	64.83	62.56	6.40	6.72	6.56	7.60	7.34	7.47
Mo_1	65.93	65.29	65.62	75.93	79.88	77.90	7.99	8.04	8.01	9.08	8.71	8.89
Mo_2	56.81	58.23	57.51	64.49	70.61	67.55	6.95	7.30	7.13	8.09	7.96	8.02
SEm ±	1.64	1.69	1.18	1.79	2.11	1.39	0.24	0.23	0.16	0.25	0.22	0.17
CD at 5%	4.72	4.87	3.33	5.15	6.08	3.91	0.69	0.66	0.47	0.73	0.63	0.48
Rhizobium												
R_0	55.92	55.41	55.68	62.43	67.03	64.73	6.71	6.89	6.78	7.96	7.67	7.77
R_1	62.36	62.79	62.53	71.36	76.52	73.94	7.52	7.82	7.67	8.85	8.34	8.49
SEm ±	1.34	1.38	0.96	1.46	1.73	1.13	0.20	0.19	0.14	0.21	0.18	0.14
CD at 5%	3.85	3.98	2.72	4.20	4.96	3.20	0.56	0.54	0.38	0.60	0.52	0.39
CV (%)	11.79	12.17	11.98	11.36	12.50	11.99	14.25	13.24	13.74	13.11	11.65	12.42

Potassium Uptake: It is evident from the data (Table 6) that magnitude of increase in K uptake by pods and haulm in pooled results was 20 and 11.6 per cent in pod and 17.4 and 9.2 per cent in haulm at 10 kg ha^{-1} iron application over control and 5 kg Fe ha^{-1}, respectively. Significantly higher uptake of K by groundnut pods and haulm noted under application of Mo @ 1 kg ha^{-1} during both the individual years and in pooled. On pooled basis the magnitude of increase in results were 19.0 and 11.6 per cent in pod and 17.4 and 7.9 per cent at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. Higher uptake of K due to Mo application might be due to involvement of Mo in BNF coupled with improvement in yield of groundnut. The results are supported by Bhagiya *et al.* (2005) [3]. Potassium uptake by groundnut pods and haulm improved significantly due to seed inoculation with *Rhizobium* during both the individual years as well as in pooled. On pooled basis the magnitude of increase in uptake was 11.3 and 8.7 per cent in pod and haulm, respectively over no inoculation. The beneficial effect of *Rhizobium* inoculation on K uptake might be due to combined effect of increased K content coupled with improvement in yield. Similar findings were also supported by Meena *et al.* (2013) [13].

Sulphur Uptake: The data (Table 6) revealed that S uptake by pods and haulm increased significantly with iron application. The magnitude of increase in pooled results were 29 and 17.7 per cent in pod and 30.4 and 14.4 per cent in haulm at 10 kg Fe ha^{-1} application over control and 5 kg Fe ha^{-1}, respectively. This might be due to increased availability of physiologically active iron in plant which in turn affected various physiological processes in plants effectively. The beneficial effect of Fe application on S uptake was also reported by Meena *et al.* (2013) [13]. Significantly higher S uptake by groundnut pods and haulm reported under application of Mo @ 1 kg ha^{-1}. On pooled basis the magnitude of increase in results were 20.2 and 12.4 per cent in pod and 18.5 and 10.3 per cent at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. S uptake by groundnut pods and haulm improved significantly under the influence of seed inoculation with *Rhizobium* during both the individual years as well as in pooled. On pooled basis the magnitude of increase in uptake was 12.1 and 8.9 per cent in pod and haulm, respectively over no inoculation.

Table 6: Effect of iron, molybdenum and *Rhizobium* on potassium and sulphur uptake by groundnut kernel and haulm

Treatments	Potassium uptake (kg ha^{-1})						Sulphur uptake (kg ha^{-1})					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	11.9	12.1	12.0	31.6	32.8	32.2	2.60	2.64	2.62	4.63	4.78	4.70
Fe_5	12.8	13.0	12.9	33.9	35.2	34.6	2.87	2.87	2.87	5.31	5.42	5.36
Fe_{10}	14.3	14.4	14.4	37.1	38.3	37.8	3.29	3.47	3.38	6.14	6.12	6.13
SEm ±	0.4	0.4	0.3	0.8	0.8	0.6	0.08	0.10	0.07	0.17	0.12	0.10
CD at 5%	1.0	1.0	0.7	2.4	2.4	1.7	0.22	0.30	1.18	0.48	0.36	0.29
Molybdenum (kg ha^{-1})												
Mo_0	12.0	12.1	12.1	31.6	32.6	32.1	2.68	2.75	2.71	4.94	4.99	4.97
Mo_1	14.4	14.3	14.4	37.5	38.0	37.7	3.25	3.27	3.26	5.89	5.89	5.89

Mo_2	12.6	13.1	12.9	33.5	35.8	34.7	2.83	2.97	2.90	5.25	5.44	5.34
SEm ±	0.4	0.4	0.3	0.8	0.8	0.6	0.08	0.10	0.07	0.17	0.12	0.10
CD at 5%	1.0	1.0	0.7	2.4	2.4	1.7	0.22	0.30	1.18	0.48	0.36	0.29
Rhizobium												
R_0	12.4	12.4	12.4	32.7	34.1	33.4	2.78	2.81	2.79	5.12	5.21	5.17
R_1	13.7	14.0	13.8	35.7	36.9	36.3	3.06	3.19	3.13	5.60	5.67	5.63
SEm ±	0.3	0.3	0.2	0.7	0.7	0.5	0.06	0.08	0.53	0.14	0.10	0.09
CD at 5%	0.8	0.8	0.6	2.0	1.9	1.4	0.18	0.24	0.15	0.39	0.29	0.24
CV (%)	11.61	11.46	11.54	10.45	9.87	10.18	11.35	14.58	13.11	13.24	9.65	11.56

Iron Uptake: The data (Table 7) revealed that on pooled basis the magnitude of increase in Fe uptake was 25 and 12.9 per cent in pod and 22.9 and 11.9 per cent at 10 kg Fe ha^{-1} application over control and 5 kg Fe ha^{-1}, respectively. Iron application in soil improves nutritional environment in rhizosphere which leads to higher absorption of nutrients by plants. The beneficial effect of Fe application on Fe uptake was also reported by Doodhwal *et al.* (2020) [6]. **S**ignificantly higher Fe uptake by groundnut pods and haulm reported with Mo application @ 1 kg ha^{-1} during both the individual years and in pooled. On pooled basis the magnitude of increase in results were 15.9 and 11.3 per cent in pod and 16.4 and 9.5 per cent at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. Fe uptake by groundnut pods and haulm improved significantly under the influence of seed inoculation with *Rhizobium* during both the individual years as well as in pooled.

Manganese Uptake: A perusal of data (Table 7) revealed that increasing level of iron application significantly increased Mn uptake by pod in first year and pooled but the results for Mn uptake by haulm were non-significant. The magnitude of increase in Fe uptake was 16.3 and 7.5 per cent in pod with 10 kg Fe ha^{-1} application over control and 5 kg Fe ha^{-1} in 2021 and pooled, respectively. Significantly higher Mn uptake by groundnut pods and haulm reported with Mo application @ 1 kg ha^{-1} during both the individual years and in pooled. On pooled basis the magnitude of increase in results were 20.2 and 12.7 per cent in pod and 19.1 and 12.4 per cent at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. Mn uptake by groundnut pods and haulm improved significantly under the influence of seed inoculation with *Rhizobium* during both the individual years as well as in pooled. On pooled basis the magnitude of increase in uptake was 12.4 and 6.5 per cent in pod and haulm, respectively over no inoculation.

Table 7: Effect of iron, molybdenum and *Rhizobium* on Iron and Manganese uptake by groundnut kernel and haulm

Treatments	Iron uptake (g ha^{-1})						Manganese uptake (g ha^{-1})					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	565	564	565	1524	1543	1534	70.4	75.4	72.9	231	234	233
Fe_5	617	630	624	1673	1688	1680	78.2	79.7	78.9	241	240	240
Fe_{10}	702	722	711	1864	1898	1882	86.3	83.2	84.8	243	242	242
SEm ±	17	17	11	43	39	32	2.2	2.6	1.7	7	5	4
CD at 5%	50	49	37	124	111	87	6.4	NS	4.9	NS	NS	NS
Molybdenum (kg ha^{-1})												
Mo_0	584	586	585	1587	1571	1579	72.4	72.3	72.4	221	220	220
Mo_1	692	696	694	1819	1850	1835	86.7	87.3	87.0	263	261	262
Mo_2	608	634	613	1655	1707	1681	75.8	78.6	77.2	231	236	233
SEm ±	17	17	11	43	39	32	2.2	2.6	1.7	7	5	4
CD at 5%	50	49	37	124	111	87	6.4	7.6	4.9	20	15	12
Rhizobium												
R_0	601	609	605	1629	1652	1641	74.2	74.3	74.3	230	231	231
R_1	655	668	661	1745	1767	1756	82.4	84.5	83.5	246	247	246
SEm ±	14	14	9	35	32	25	1.8	2.1	1.4	6	4	3
CD at 5%	41	40	27	102	91	74	5.3	6.2	4.0	16	12	10
CV (%)	11.75	11.41	11.58	10.89	9.62	10.26	12.13	14.06	13.15	12.60	9.01	10.95

Zinc uptake: A perusal of data (Table 8) revealed that increasing level of iron application significantly increased Zn uptake by pods but the results for Zn uptake by haulm were non-significant. On pooled basis the magnitude of increase in Zn uptake was 13.1 and 6.3 per cent in pod at 10 kg Fe ha^{-1} application over control and 5 kg Fe ha^{-1}, respectively. **S**ignificantly higher Zn uptake by groundnut pods and haulm reported with Mo application @ 1 kg ha^{-1} during both the individual years and in pooled. On pooled basis the magnitude of increase in results were 18.2 and 11.8 per cent in pod and 16.7 and 10 per cent at 1 application over control and 2 kg Mo ha^{-1}, respectively. Similar findings were also reported by Khan and Prakash (2013) [11]. Zn uptake by groundnut pods and haulm improved significantly under the influence of seed inoculation with *Rhizobium* during both the individual years as well as in pooled. On pooled basis the magnitude of increase in uptake was 10.2 and 8.6 per cent in pod and haulm, respectively over no inoculation. Similar findings were also reported by Khan and Prakash (2013) [11].

Molybdenum uptake: A perusal of data (Table 8) revealed that on pooled basis the magnitude of increase in Mo uptake was 20.9 and 10.9 per cent in pod and 17.3 and 8.5 per cent at 10 kg ha^{-1} iron application over control and 5 kg Fe ha^{-1}, respectively. Increase in uptake of Mo by pod and haulm might be due to more yield and nutrient content in groundnut due to Fe application. Similar findings were also reported by Singh *et al*. (2004) [15]. It is clear from the data presented in Table 4.50 that significantly higher Mo uptake by groundnut pods and haulm reported with Mo application @ 1 kg ha^{-1} during both the individual years and in pooled. The results of Mo uptake by groundnut haulm with 1 kg ha^{-1} was at par with 2 kg ha^{-1} during both the individual years as well as in pooled. On pooled basis the magnitude of increase in Mo uptake was 21.2 and 6.25 per cent in pod at 1 kg Mo ha^{-1} application over control and 2 kg Mo ha^{-1}, respectively. Increase in uptake of Mo by pod and haulm might be due to more yield and nutrient content in groundnut due to Mo application. Similar findings were also reported by Kumar and Sharma (2005) [12]. Mo uptake by groundnut pod and haulm improved significantly under the influence of seed inoculation with *Rhizobium* during both the individual years as well as in pooled. The corresponding values of Mo uptake by groundnut pod was 0.77 g ha^{-1} and 1.95 g ha^{-1} in haulm in pooled. This might be due to higher yield in inoculated plots. Similar findings were also reported by Khan and Prakash (2014) [10].

Table 8: Effect of iron, molybdenum and *Rhizobium* on zinc and molybdenum uptake by groundnut kernel and haulm

Treatments	Zinc uptake (g ha^{-1})						Molybdenum uptake (g ha^{-1})					
	Kernel			Haulm			Kernel			Haulm		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1})												
Fe_0	106	107	107	183	192	187	0.69	0.65	0.67	1.67	1.80	1.73
Fe_5	111	112	112	191	197	194	0.74	0.72	0.73	1.81	1.92	1.87
Fe_{10}	118	121	119	195	200	197	0.82	0.79	0.81	1.97	2.09	2.03
SEm ±	3	4	2	6	5	4	0.02	0.02	0.01	0.05	0.05	0.04
CD at 5%	9	10	7	NS	NS	NS	0.05	0.06	0.04	0.14	0.15	0.10
Molybdenum (kg ha^{-1})												
Mo_0	104	105	104	177	181	179	0.69	0.63	0.66	1.63	1.71	1.67
Mo_1	124	123	123	206	213	209	0.81	0.78	0.80	1.94	2.06	2.00
Mo_2	108	112	110	185	195	190	0.75	0.75	0.75	1.88	2.04	1.96
SEm ±	3	4	2	6	5	4	0.02	0.02	0.01	0.05	0.05	0.04
CD at 5%	9	10	7	16	14	11	0.05	0.06	0.04	0.14	0.15	0.10
Rhizobium												
R_0	107	107	107	182	188	185	0.72	0.68	0.70	1.75	1.86	1.81
R_1	117	119	118	197	204	201	0.79	0.76	0.77	1.88	2.01	1.95
SEm ±	3	3	2	5	4	3	0.01	0.02	0.01	0.04	0.04	0.03
CD at 5%	7	8	5	13	12	9	0.04	0.05	0.03	0.11	0.12	0.08
CV (%)	10.94	13.29	12.62	12.41	10.80	11.21	9.96	12.54	11.27	11.08	11.35	11.23

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